Semi-Annual Report
July-December 1994

Frank E. Hoge
GSFC/Wallops Flight Facility/972.0
MODIS UPN: 229-01-04

A. Task Objective: Algorithm Development for Global Mapping of Phycoerythrin Pigment, Dissolved Organic Matter, and Chlorophyllous Pigment

1. MODIS North Atlantic Test Site Establishment and Characterization

As previously reported, the MODIS North Atlantic Test Site has been established as originally proposed. The Test Site includes the New York Bight/Mid-Atlantic Bight/Gulf Stream/Sargasso Sea and is conveniently located north and east of GSFC/WFF. Characterization has been initiated by ship sampling, aircraft overflights, and analysis of historical data available from within the NASA AOL project since 1980. Much of the data obtained in the northwestern portion of the test site will be used for algorithm development in Case 2 waters.

a. During this 6-month reporting period the Test Site little new data was added to the existing Test Site data base. However, the site characterization was continued with prior available data in the form of airborne active-passive ocean color data. In particular the airborne and ship data acquired during Test Site field work in cooperation with Interdisciplinary Investigator, Dr. Niel Blough (WHOI), during the field experiments in April 1994 has now completed internal quality evaluation. The data is now being staged into the on-going MODIS algorithm development effort.

The ship data needed to produce the total absorption from particulate and dissolved materials has now been essentially completed. The particulate absorption is the sum of the filter pad chlorophyllous particulates and the detritus and is yet to be separated by hot methanol procedures. The spectral absorption and fluorescence of these samples will be measured by Dr. Tony Vodacek, a former National Research Council Resident Research Associate (RRA) now working with Dr. Blough at the Univ. of Maryland.

A manuscript describing some of the algorithm work was published during the previous reporting period. The reader should consult this paper for details of the progress of the DOM retrieval using fluorescence methods. The manuscript is: Hoge, Frank E., Anthony Vodacek, Neil V. Blough, "Inherent Optical Properties of the Ocean: Retrieval of the Absorption Coefficient of Chromophoric Dissolved Organic Matter from Fluorescence Measurements", Limnology and Oceanography, 38(7) 1394-1402, 1993. A companion paper describing the retrieval of CDOM absorption coefficients has

been accepted for publication: Vodacek, Anthony, Frank E. Hoge, Robert N. Swift, James K. Yungel, Edward T. Peltzer, Neil V. Blough, The detection of in situ and airborne fluorescence measurements to determine UV absorption coefficients and DOC concentration in surface waters, Limnology and Oceanography, In Press (1994).

The validity of the Test Site samples and data were addressed during the prior reporting period. Specifically, the DOM absorption from prior cooperative ship experiments (see above paper) have been used to establish the levels of DOM fluorescence measured with the NASA Airborne Oceanographic Lidar in both the Atlantic and Pacific Oceans. These results were also published during this reporting period. The reference is : Hoge, Frank E., Robert N. Swift, James Y. Yungel, Anthony Vodacek, "Fluorescence of Dissolved Organic Matter: A Comparison of North Pacific and North Atlantic Oceans during April 1991", Jour. Geophysical Res. 98, No. C12, 22,779-22,787 (1993).

The airborne flights during April 1994 allowed the concurrent evaluation of a new 256 channel ocean color spectrometer designed and built at Wallops Flight Facility. It was found that the color sensor possessed the requisite sensitivity for ocean color spectra in a high-rate/low-integration-time mode needed to allow editing of data containing sun glint. The prototype sensor was successfully flown during the JGOFS Iron Enrichment Experiments off the coast of Ecuador in November 1993. A still higher sensitivity detector and higher resolution sensor was completed during this reporting period and plans are being developed to fly this sensor during the ship cruise overflights in April 1995 (see subsequent section).

The evaluation of a sea surface temperature sensor manufactured by Heimann/EG&G was conducted during the previous two reporting periods. Our evaluation of this sensor suggests that the precision is satisfactory for support of the validation of MODIS products and algorithms relative to sea surface temperature. The final accuracy evaluation is still pending.

2. Selection of Case 1 Data Sets.

As given in a prior report, airborne active-passive ocean color data acquired within Case 1 oceanic regions with the NASA Airborne Oceanographic Lidar have now being screened for use in algorithm development. The AOL active-passive data in the northwestern Atlantic Ocean east of St. Johns , Newfoundland (obtained in 1989 as part of the Joint Global Ocean Flux Study of the North Atlantic Bloom Experiment) displayed remarkable quality and freedom from non-chlorophyllous backscatterers and is the basis of a modeling paper to be published in Applied Optics. The title of the paper is: Oceanic radiance model development and validation: Application of airborne active-passive ocean color data. This manuscript shows that voluminous, wide-area airborne active (laser) and passive (solar) ocean color spectral data can be used to develop radiance

models and currently provide for their validation. The application of such models to algorithm development by direct inversion is under development. Such inversion was detailed in the recently developed ATBD. The St. Johns data, and that obtained in other regions of the ocean, is being used to establish the baseline radiance model to be used for the retrieval of phycoerythrin pigment (as well as DOM and pigment). Other data sets from the Monterey Bay flights (Sept 1992) and Mid- Atlantic Bight (April 1989 and 1991) are still now under evaluation.

B. Other Work Accomplished

1. Revision of the Algorithm Theoretical Basis Document (ATBD).

The ATBD revision is now nearly complete. The original (and the revised) document details a new procedure for retrieving the phycoerythrin pigment by using the absorption bands. Existing MODIS bands are expected to be sufficient to effect the retrieval.

2. Ship Data.

As reported in the above Limnology and Oceanography paper, recovery of the absorption coefficients for the light-absorbing or chromophoric components of the dissolved organic matter (aCDOM) from their fluorescence emission has been established by laboratory analyses of the surface samples gathered from the Feb. 28, 1991 cruise as well as other cruises. These absorbance and fluorescence analyses, (and work reported by others), show that absorption coefficients in the near ultraviolet can be directly retrieved from measurements of the fluorescence emission of CDOM. Thus, absorption coefficients in the visible spectrum can potentially be obtained from the fact that CDOM absorption is exponentially a function of wavelength. The errors in the laboratory fluorescence measurements were minimized through the combined use of the water Raman scatter as an internal radiometric standard and a quinine sulfate solution as a reference. This methodology reduces aCDOM algorithm retrieval errors (reported by other researchers) primarily attributable to the use of commercial spectrophotometers having maximum optical path lengths of 10 cm. While the aCDOM retrieval appears feasible, the relationship between aCDOM and CDOM fluorescence emission is susceptible to changes in CDOM fluorescence yield, so the continued temporal study of marine samples from many diverse oceanic locations is needed. When applied to shipboard and aircraft laser fluorometers, this retrieval methodology and the resulting CDOM absorption coefficients will be used in ocean color models and associated satellite sensor/algorithm development directly aimed at phycoerythrin retrieval. The DOM is important since it is a major interferant to the detection and quantification of chlorophyll and chlorophyll accessory pigments (CAP) such as phycoerythrin. Moreover, DOM is a contributor to the carbon cycle itself.

Recent laboratory and resulting analytical efforts have shown that

the retrieval of dissolved organic carbon from absorption or from fluorescence emission still needs considerable work to prove feasibility.

2. In Situ Optical Characterization of the MODIS North Atlantic Test Site.

The continued characterization of the Test Site is partially described in the previously mentioned publications.

A. Cooperative overflights within the MODIS Test Site were conducted during April, 1994 in conjunction with shipboard sampling activity conducted by Dr. N. Blough, an EOS Interdisciplinary Team member and in conjunction with additional shipboard sampling activity by Dr. Dan Repeta (WHOI) in conjunction with the DOE Coastal Ocean Program. The shipboard phycoerythrin fluorescence experiments of Dr. N. Blough with the flow-thru spectrometer were unsuccessful but will be tried again during subsequent field experiments.

1. Phycoerythrin Algorithm Development Activities
Plans call for us to again directly address the quantification of the phycoerythrin signal as outlined in the original MODIS proposal. The phycoerythrin retrieval is being dealt with by inversion of ocean radiance models. Details of the phycoerythrin retrieval appear in the ATBD as submitted the project office.

2. Chlorophyll Pigment and CDOM Corrections to the Phycoerythrin Algorithm.

Major perturbations or influence to the ocean color spectrum are provided by chlorophyll and CDOM. These oceanic constituents significantly impede the retrieval of phycoerythrin pigment from the upwelled radiances. Accordingly, they must be dealt with in a systematic way in order to understand their effects and the impact on the retrieval of phycoerythrin and its ultimate quantification. In situ and airborne data gathered to date will be used to model the effects and to ascertain the extent that they can be quantified and removed. Recently published chlorophyllous pigment models are being used for the pigment absorption. Our own CDOM model is being used for recovery of chromophoric dissolved organic matter. Finally, the literature is being surveyed for the best available detritus absorption model. The most pressing modeling problem is the availability of suitable chlorophyllous and nonchlorophyllous particulate backscatter models.

3. Other Data Acquisition for Algorithm Development

During late October and early November 1993 flights were conducted in cooperation with NSF's Joint Global Ocean Flux Study of Iron Enrichment in the Eastern Equatorial Pacific. Considerable Case 1 ocean color data was obtained during these JGOFS flights both during the mapping of the ship-deployed iron and during the transit to and from the experiment site at -90W

and -5S. Quality algorithm-development ocean color data was also obtained on pre-determined transects within the naturally-occurring Galapagos Island plume. The transit flights from Wallops Flight Facility to Guayaquil (via Belize) likewise yielded ocean color data suitable for algorithm development. During the latter transit flights, numerous watermasses were crossed. These data are being evaluated.

In addition to the previously reported airborne data acquired over the cruise of Dr. Blough, overflights of Dr. Tom Fisher/Dr. Larry Harding (Horn Point Environmental Laboratory/Univ. Md.) together with Dr. Frank Muller-Karger were conducted in the region extending from the Chesapeake Bay mouth to Cape Hatteras.

The above data are likewise undergoing evaluation for possible use in algorithm development.

C. Anticipated Activities During Next Half Year.

1. Additional flights of the NASA Airborne Oceanographic Lidar are planned within the MODIS Test Site. Specifically, overflights of cruises of the Research Vessel Cape Henlopen by Dr. Richard Geider and Dr. Jon Sharp of the University of Delaware are planned for April 1995. These field experiments will occur in the same general region as those of Dr. Blough in April 1994. We are hopeful that Dr.'s Blough and Vodacek can also participate in the April 1995 field experiments.

2. Preparations are being made to participate in the JGOFS Arabian Sea Experiment in July 1995. This is an opportunity to obtain data in an entirely different oceanic province. As was the case with the Iron Enrichment Experiment flights, these flights will serve as a valuable data source for algorithm development. This activity should contribute to the goal for universality of the algorithms being developed.

D. Other Concerns

As in a past report some good news is reportable. The lack of a 600nm band on MODIS-N was given as the biggest problem facing the retrieval of the phycoerythrin pigment on the first sensor launch. Recent studies of available radiance (and reflectance) models, however, suggests that the retrieval of the phycoerythrin pigment at the absorption peaks of 495nm (phycourobilin, PUB) and 545nm (phycoerythrobilin, PEB) can be achieved using the 490nm and 555nm MODIS bands. Such retrievals will require a highly accurate model to account for the significant amounts of chlorophyll and DOM absorption occurring simultaneously with the phycoerythrin absorptions. The details of the phycoerythrin retrieval have been recently detailed in the ATBD.